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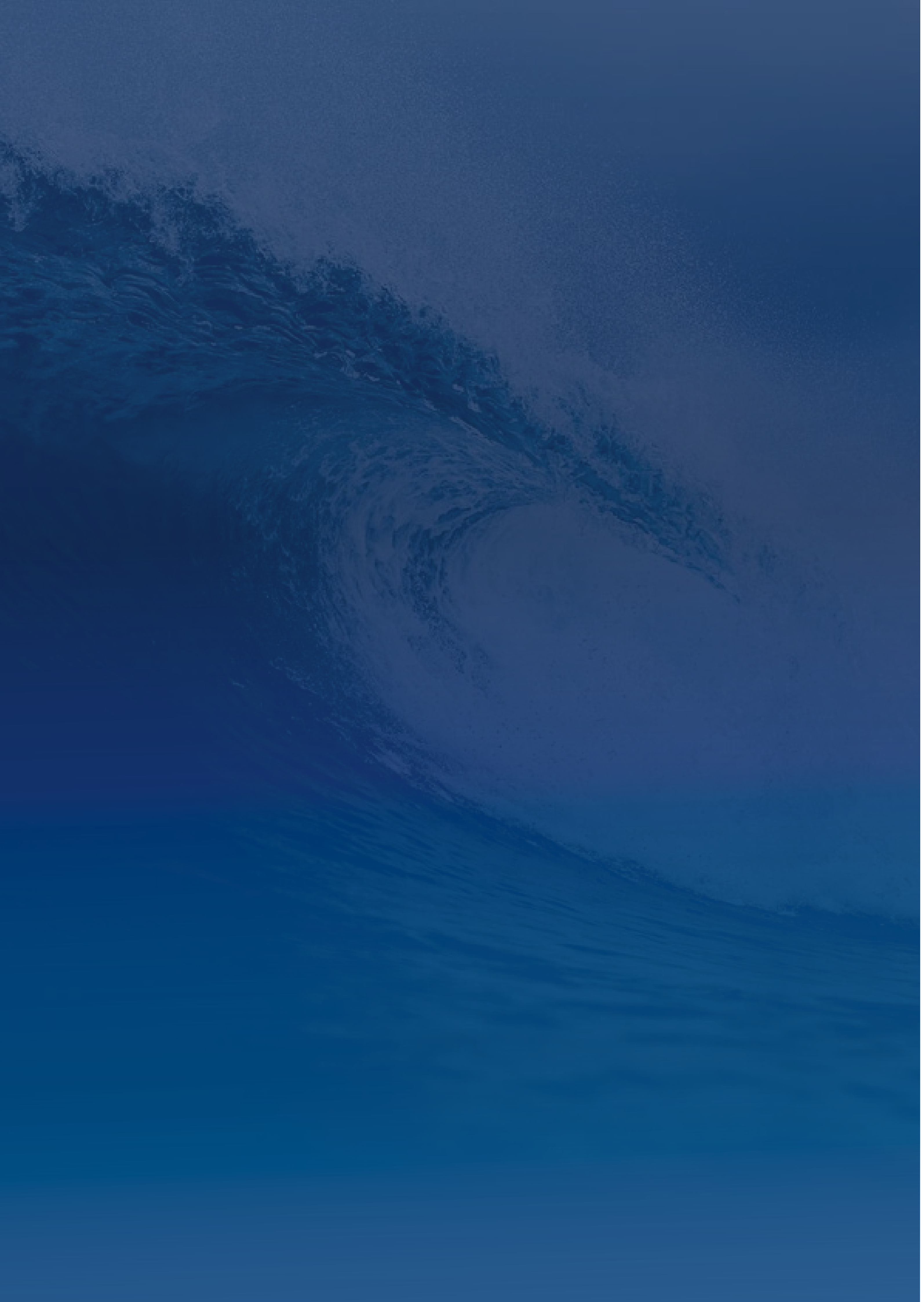
NMCI
National Maritime College of Ireland
Coláiste Náisiúnta Mara na hÉireann

Leaving Certificate Special Topic **Prescribed 2024**

Design, Operation & Technology of Container Ships

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University



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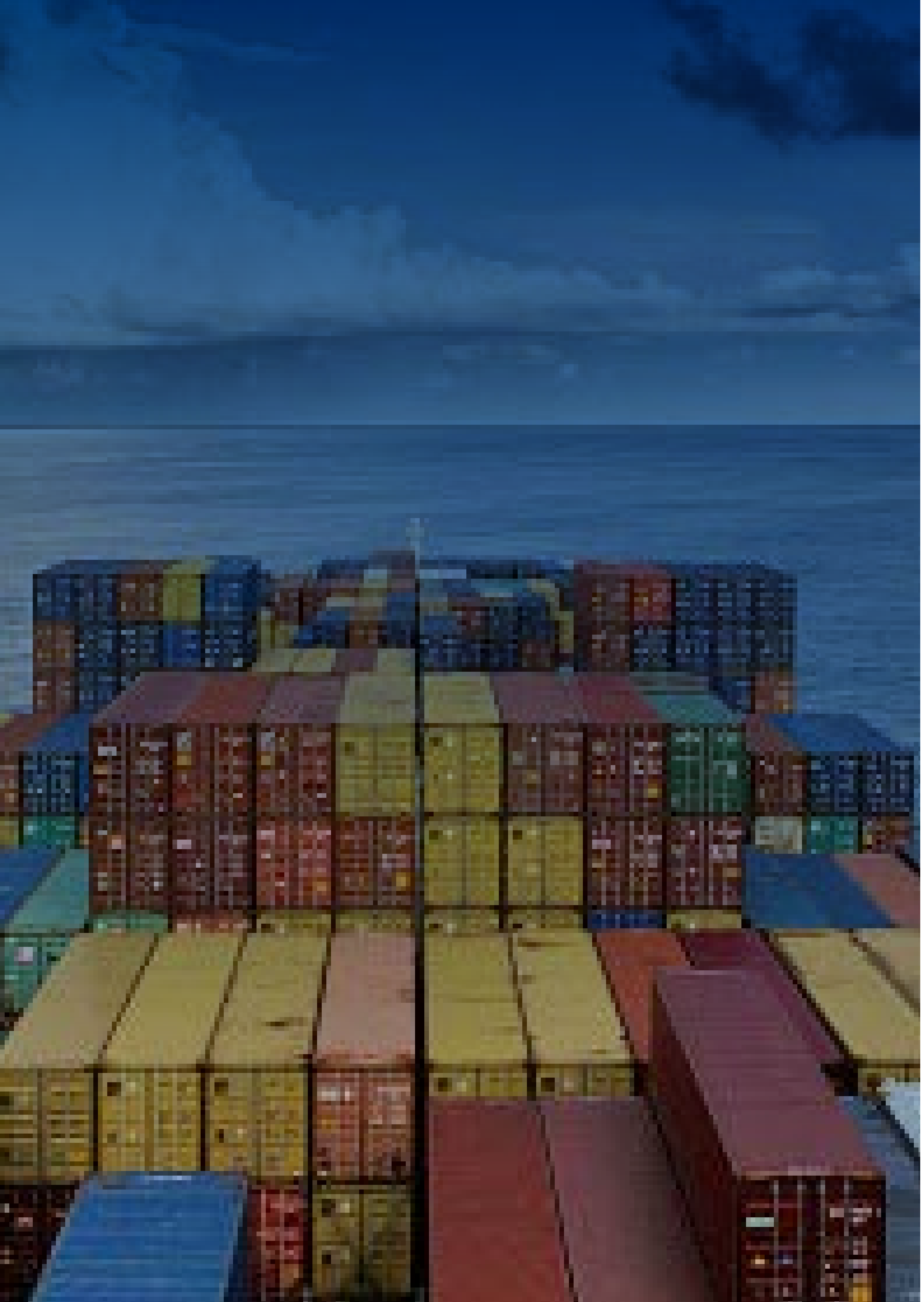

Foreword

Ireland, an island nation, relies on the sea for circa 95% of its trade by value and volume. The maritime industry is a critical enabler for sustaining Ireland's national economy across several sectors. The 'shipping container', due to its inherent simplicity and robust design, provides a wide range of applications across different modes of transport, ranging from ship to rail to truck.

The following paper will provide an overview of how this shipping feat of engineering has transformed global supply chains, focusing on the design, operation, and technology of a containership. Today's containerships, on a voyage from China to Europe, produce around the same CO_2 emissions as that of European long-haul truck if it were to carry the same container only two hundred kilometres.

Notwithstanding the impact the containership has had on shipping and modern society, this technology would not be capable of achieving such achievements without the embarkation of highly trained ships officers and crew. The National Maritime College of Ireland (NMCI) is mandated to provide aspiring seafarers with Maritime Education and Training in preparation for undertaking demanding challenges, such as being Captain or Chief Engineer of a Containership. The NMCI is Ireland's only purpose-built facility for training mariners with full mission bridge simulators, environmental pool, and engineering workshops and laboratories, providing trainee deck, engineering & electrotechnician officers with the knowledge and skills to excel in the maritime industry. As a constituent college of Munster Technological University, the NMCI provides the following degree programmes; BSc Nautical Science (MT766), BEng Marine Engineering (MT764) and BEng Marine Electrotechnology (MT765).

Marine Electrotechnology | Marine Engineering | Nautical Science

These qualifications can lead to multiple career opportunities such as ships officers, surveyors, careers in law and the renewable energy sector. Life at sea will appeal to those who would like to combine travel with their career and the NMCI produces graduates who are sought worldwide by shipping companies. The industry is looking for capable and enthusiastic people who are ready for responsibility and who enjoy using thea latest technology, thus generating a significant demand for qualified personnel to manage and operate the technology of today's sophisticated ships with commensurate levels of pay and attractive benefits packages.

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Sinéad Reen
Head of Dept. of Maritime Studies
National Maritime College of Ireland
Munster Technological University

1. Introduction to special topic

Container ships are a crucial component of modern global trade, and they have evolved significantly in terms of design, operation, and technology. The development of containerships has been a transformative engineering achievement that has had a profound impact on the world economy. It has made international trade more accessible, affordable, and efficient, allowing us to enjoy access to a wide variety of goods from around the world. The continual growth in the size and capacity of container ships reflects the ongoing changing of the industry to meet the demands of global trade.

In this topic we will look at containership development, design, size, operational aspects, propulsion, environmental considerations, and safety systems.

2. Development of the container ship concept

In the 1950s, entrepreneur Malcolm McLean revolutionised the shipping industry by developing the shipping container. The containers were designed to be compatible with various modes of transportation, meaning that goods could be seamlessly transported from a factory to a ship, then to a truck or train, and finally to their destination without being unpacked. This greatly reduced cargo handling costs, increased efficiency, and accelerated global trade.

He took a World War II T2 tanker (oil carrying ship) and converted it into the first containership, the SS Ideal X. He based the size of the cargo carrying box on the standard truck size in the USA at that time.

The SS Ideal X sailed on her first (container carrying voyage) in 1956 carrying a mere 58 boxes, it was a concept that eventually exceeded all expectations. Container dimensions were standardised with the agreed standard based on a 20-foot length container, the term we are now most familiar with is the Twenty Foot Equivalent Unit (TEU).

Figure 1: Container being lifted off a truck to be loaded on the ship, source Captain Peter Walter.

The image above shows the intermodal versatility of container shipping.

The size of a containership refers to the number of TEUs that she can carry. The types of containers in use and carrying capacity of containerships has evolved. Where once an 800 TEU ship was considered big, the containership size has now exceeded 24,000 TEU.

See the following YouTube clip of Richard Hammond on one of the largest containerships in the world - it gives a snippet of the life of a large container ship.

https://www.youtube.com/watch?v=l2JMaJTFSvw

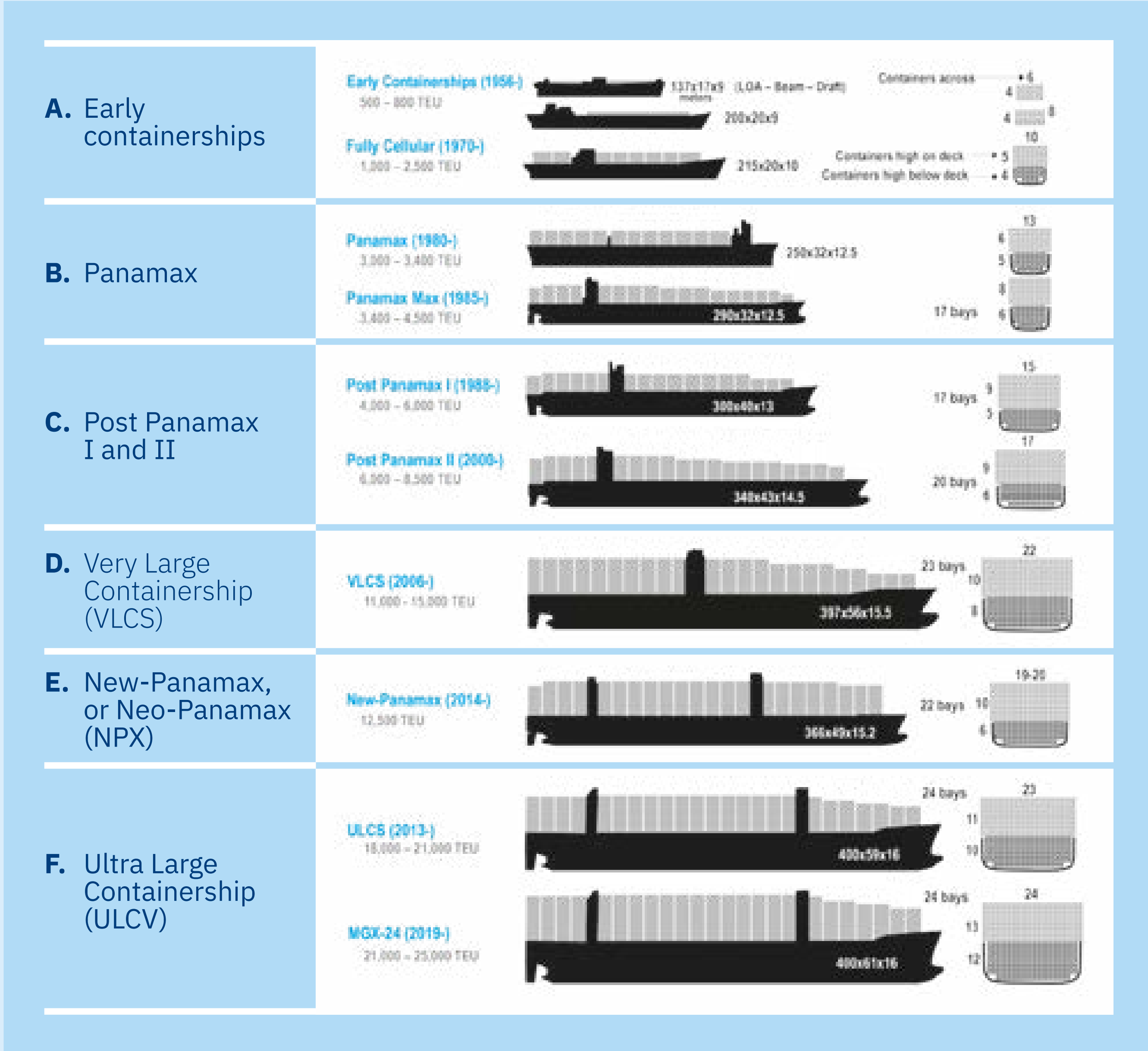
Putting the rapid development in perspective, 80% of world goods are carried by sea, an estimated 250million containers are shipped annually. By 2028 the container shipping industry is estimated to be worth $16billion USD's.

Further information can be found on the following two links:

http://transportgeography.org/contents/chapter5/maritime-transportation/evolution-containerships-classes/

https://www.inboundlogistics.com/articles/container-ship/

Figure 2: Timeline of development of container ships.



3. Design

3.1 Hull design

Containerships are designed to be fast and efficient both in terms of their voyage from one port to another and the speed at which the cargo is loaded and discharged.

For speed and efficiency at sea they require a hull shape that optimises fuel consumption and enhances hydrodynamic performance. The hull design must also allow for maximum cargo carriage. To achieve this the main body of the hull is rectangular shape whereas the bow (front) and stern (aft) are more curved to ensure a smooth flow of water past and away from the vessel.

To ensure efficiency whilst in port there must be easy access to containers both above and below decks. Containers below decks don't require securing as they are kept in place by cell guides. These guides are basically metal structures that run from the bottom of the cargo hold to the top.

The image below shows a typical container hold below deck level with cell guides.

Figure 3: Typical containership cargo hold showing cell guides, source Captain Colin Fardy.

The link following gives an overview of the construction of a modern containership, including showing the modular construction techniques, where large sections are built in different parts of the shipyard and they are assembled in one location.

https://www.youtube.com/watch?v=KVGkqFCYIHc

The Reedi website has a virtual model of a container ship. Take a look and explore.

https://reedi.ie/reedi-programme/mechanical-and-manufacturing-engineering/leaving-cert-engineering-prescribed-topic/

3.2 Container ship size

The growth in container ship size was driven by economies of scale, the more of something you can transport the less the overall cost, hence the reason for 24,000 TEU ships.

It is interesting to note that the fuel consumption does not scale up with the ship size. Doubling the amount of cargo she can carry does not double the fuel consumption. On the other hand, increasing ship speed results in a marked increase in fuel consumption. Thus, increasing the ship size rather than ship speed gives greater economy of scale, meaning it becomes cheaper to ship more rather than less and thus the desire to have bigger and bigger container ships.

The following link shows some of the largest container ships in the world.

World's Largest Shipping Container Ships in 2023 | SCF

But there is still a need for container ships of a small size. Larger containerships are restricted to docking at certain ports due to quay (berth) size, cranes and the available depth of water within the port. Smaller ships are employed to connect trade between larger and smaller ports.

The Panama canal is an example of where there are restrictions - big containerships can't fit in and although they have increased the size of locks within the canal there are still limits.

To understand the size of a large containership, stand her next to the Eiffel Tower and she could be 70m taller than the Eiffel Tower (so she is about 4 soccer pitches in length!).

For illustration on the size of a large containership, see the following link:

https://www.youtube.com/watch?v=qR22ISvBpBM

The following link explains the different types of container ships:

https://www.inboundlogistics.com/articles/container-ship/

The figure below shows the growth in size of container ships and cargo carrying capacities from the early 1960's to the present day.

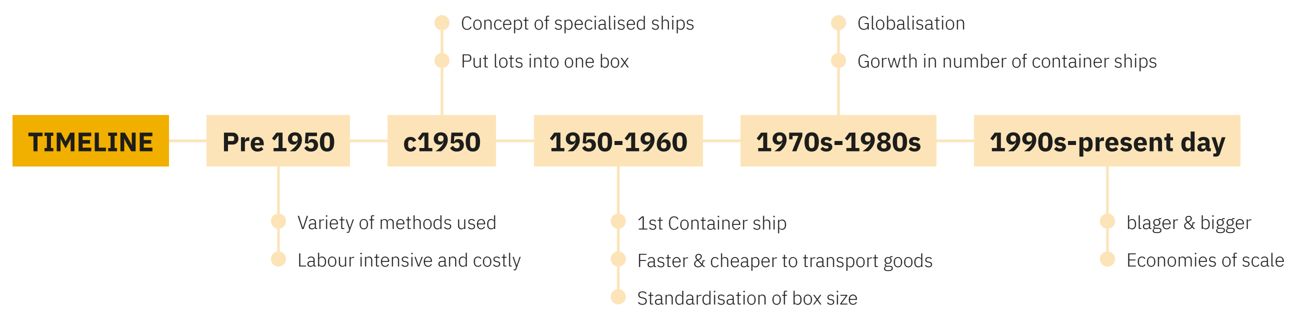


Figure 4: Growth in containership size. Source The Geography of Transport Systems

4. Operational

4.1 Ship stability

A vessel is designed to float upright under normal conditions. If an external force such as wind or waves causes the vessel to heel (lean over) at some angle it should return to the upright condition - this is what is meant by stability.

If we sit in a kayak, we need to sit in the middle (on the centreline) otherwise it would become unstable. Sitting anywhere other than the centreline and its centre of gravity becomes offset to one side. Stand up and it becomes unstable as the centre of gravity becomes too high. The result? Most likely it falls over (capsizes).

Stability is the function of two things:

- The position of the centre of gravity - the higher the centre of gravity the less stable the vessel is (standing up in a kayak) and the lateral position of the centre of gravity (try leaning to one side in a kayak)
- The underwater shape of the hull is the other factor - the kayak is not very stable because it has a narrow hull whereas a larger boat is more stable.

The same basic principle applies to a ship. The naval architect (ship designer) generates stability data from the hull shape and produces a 'Stability Book'. They also determine the centre of gravity of the ship without cargo or any other items. The actual centre of gravity (and hence the ship stability) is calculated by a 'Loading Computer' using the information from centres of gravity of added weights (such as containers, and fuel) and hull data.

4.1.1 Measurement of a ship's stability (GM)

The term GM is mentioned a lot regarding ship stability. GM is simply how the stability of a vessel is measured. It can be too high, too low or even negative, negative means she falls over (capsizes).

Too large a GM & the vessel is considered 'stiff', meaning she will roll rapidly from side to side. This does not alone cause stress on the ship it increases the stresses on the container securing devices and may lead to loss of containers.

Too small a GM & the ship is considered 'tender', meaning she will roll very slowly from side to side and if there are heavy seas they are more likely to pour over the ship's side and onto the deck.

So, the optimum is to find a balance somewhere in the middle.

This is achieved by correct stowage of cargo and supplemented with distribution of ballast water in the ship's ballast tanks i.e., putting weight lower down.

The following link explains what happens 'when it goes wrong':

https://www.youtube.com/watch?v=rL8yHHR0J-8 YouTube

More detailed information on ship stability can be found on the following link:

https://tc.canada.ca/en/marine-transportation/marine-safety/3-stability-0

4.1.2 Ship motion and stresses

A ship in a seaway can roll from side to side, heave up and down, twist, bend and never uniformly. In fact, different parts of the ship will experience different forces at the same time.

There are 6 degrees of motion that need to be considered, the 3min YouTube clip explains them.

https://nautiluslive.org/video/2020/12/09/beyond-wow-six-types-ship-motion

The following YouTube video explains the twisting and torsional effects (watch from 3:18 to 4:40)

https://www.youtube.com/watch?v=pNdughfkDbM YouTube

Then watch the following clip to see torsional effects on a container ship in a storm- see the deck and ship flexing!

https://www.dailymotion.com/video/x2afw2u

4.2 Cargo operation

Planning the cargo operations on a container ship is complex. A planner working ashore will plan which containers are to be loaded or discharged in the various ports along the ship's route. It is like a 3D puzzle or game of 'Tetris'.

The complexity comes from the numerous ports of call. Containers for the 2nd port of call cannot be loaded onto containers for the 1st port of call. Heavy containers cannot be placed on top of light containers. Refrigerated containers need to be plugged into the ship's power source. Containers carrying dangerous goods can only be placed in certain areas due to their hazardous nature.

So, load planning is a combined effort from both ashore and the ship, made easier nowadays thanks to technology.

See this link for a visual explanation of cargo operations on container ships:

https://www.youtube.com/watch?v=kj7ixi2lqF4 YouTube

On the next page Figure 5 shows refrigerated and standard containers and the securing bars.

Figure 5: Refrigerated and standard containers stowed on deck, source Captain Colin Fardy.

Figure 6: Navigating console on the bridge, reference Captain Franz Holmberg.

4.3 Navigation

Navigation of the vessel is undertaken from a space onboard known as 'The Bridge'. Modern technologies have transformed the bridge of a ship, making it more efficient, safer, and equipped with advanced navigation, communication, and control systems. Ships also use GPS for position fixing. We even have virtual roundabouts and roadways at sea! Figure 6 is a photo of the integrated bridge system console on a modern containership.

Figure 7: The Bridge of a modern containership, reference Captain Colin Fardy.

5. Engineering

Engineering clearly brings to mind the propulsion of the ship, but it actually encompasses a wide range of other systems and equipment required to operate the ship. A brief description of some of these systems is given here.

This video gives an overview of a large merchant ship's engine room:

https://www.youtube.com/watch?v=s7BhBsVigZw

5.1 Propulsion - slow speed two-stroke diesel engines

The slow-speed two-stroke engine is unique to ship propulsion. It is a large bore (600 - 900 mm) and long stroke. There is no clutch or gearbox - the engine drives the propeller directly. If the ship needs to go astern the engine is actually stopped and then started in the reverse direction.

This video gives a good overview of the scale of these engines.

https://www.youtube.com/watch?v=k0u2lhV4K6E

Figure 8 is of the main engine of a containership.

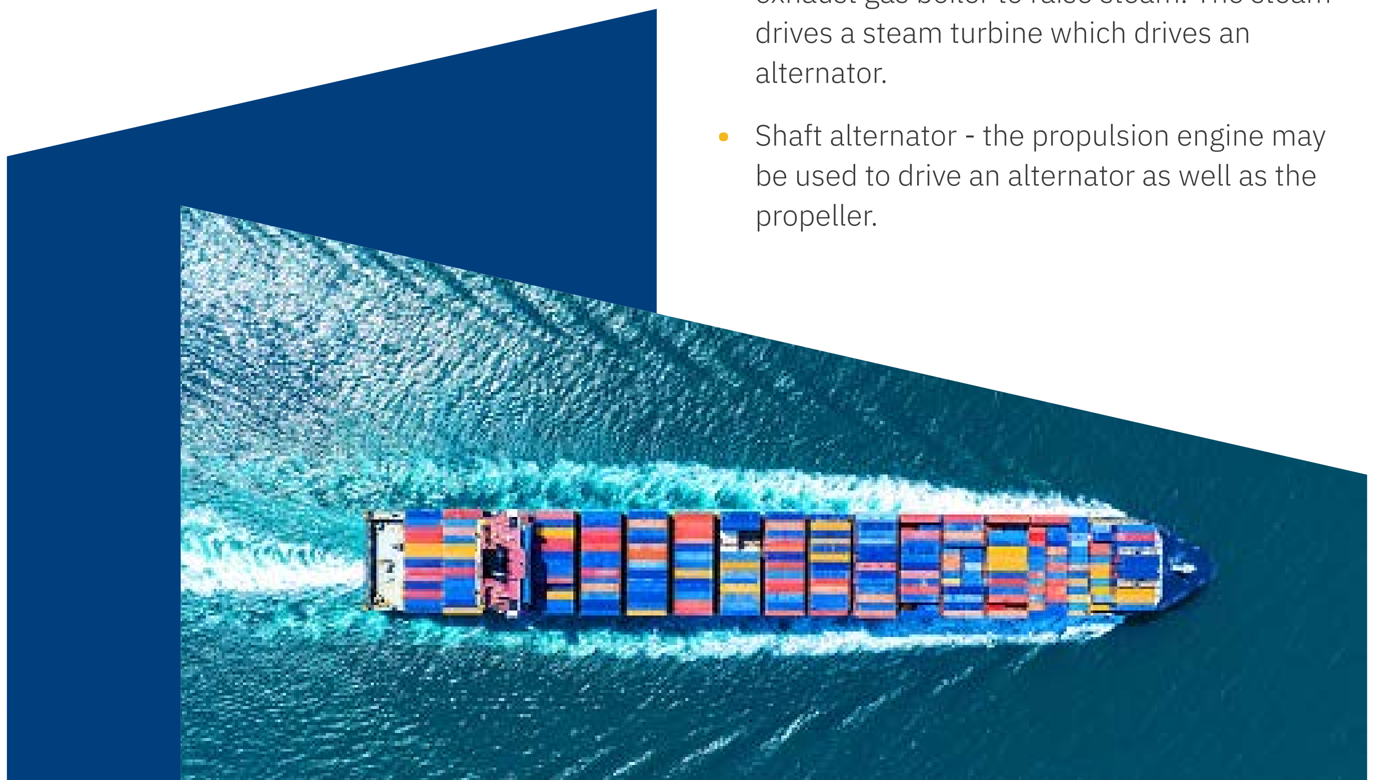


Figure 8: Ship's main engine undergoing maintenance, source Captain Mark Maguire.

5.2 Electrical power

Electrical power is needed throughout the ship to drive motors for all the auxiliary systems and power all other electrical systems. This power is provided by one or more of the following:

- Diesel alternators - a diesel engine driving an alternator.
- Turbo alternator - waste heat from the propulsion engine exhaust is used in an exhaust gas boiler to raise steam. The steam drives a steam turbine which drives an alternator.
- Shaft alternator - the propulsion engine may be used to drive an alternator as well as the propeller.

5.3 Steering

Clearly steering the ship is as important as propulsion and very large forces are required to turn the ship's rudder. This is done by a machine known as the 'steering gear'. The rudder is like a vertical hinged paddle behind the propellor.

This video illustrates the operation of electro-hydraulic steering gear.

https://www.youtube.com/watch?v=99PkWjURKTY

Figure 9 is of a propellor and rudder arrangement.

Figure 9: Ship's propellor and rudder arrangement, source Captain Mark Maguire.

6. Environmental protection

Shipping has environmental impacts and mitigating these impacts is a key engineering function. Some examples of the systems you will find on board are:

6.1 Ballast water management

Ships take on ballast water for several reasons (stability, ensuring propeller and rudder are immersed, limiting hull structural loading). This ballast water is discharged during loading cargo. The result is water from one coastal zone is taken up and discharged in a different coastal zone. This can result in the introduction of Invasive Aquatic Species (IAS) to coastal zones. The ballast water must be treated to mitigate this risk. Follow this link for more information on this issue.

https://archive.iwlearn.net/globallast.imo.org/ballast-water-as-a-vector/index.html

6.2 Ship motion and stresses

Oil contaminated water has a serious impact on the marine environment. Oil leakage can occur in the machinery spaces, and this contaminates any water in the bilges. It is necessary to separate any oil from bilge water before it is discharged overboard (the maximum limit is currently 15 ppm). A number of technologies are employed to achieve this, most are based on the density difference between oil and water.

6.3 Gaseous emissions

The combustion of fuel oil in diesel engines leads to several gaseous emissions:

- The fuel contains sulphur and combustion leads to oxides of sulphur which, in combination with moisture, form acids. There are international standards limiting the amount of sulphur permitted in marine fuels at sea and in port. 'Scrubbing' systems may use water sprays to reduce this gaseous emission.

- The high carbon content of fuel oil results in high CO_2 emissions. Several strategies are being employed to reduce these emissions. Improving engine efficiency is an obvious approach but it is technically challenging. Employing alternative fuels with lower carbon content is the main thrust of current research. Liquid Natural Gas (LNG), methanol, ammonia and hydrogen are all either in current use or planned as future fuels. There are significant technical challenges in the storage, handling, and combustion of these alternative fuels.
- Combustion of fuel in a diesel engine occurs at high temperatures and this results in the production of NOx. This actually has a much higher impact than CO_2. Two technologies are in use to reduce NOx emissions - Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR).

7. Safety systems

Fire safety on board ship is a major concern. While at sea the ship crew must be capable of dealing with any fire that occurs. This fire could be in accommodation spaces, machinery spaces or cargo spaces. Several methods are employed to reduce the risk of fire. Structural boundaries are designed to contain a fire in its place of origin, fire detection systems are designed to detect a fire and its location and firefighting systems are employed to extinguish the fire.

Firefighting Systems:

- **Fire pumps and fire main** - a dedicated piping system supplies hydrants throughout the ship. Hoses and nozzles are available at each hydrant. The water is supplied from dedicated fire pumps in the engine room and an independent fire pump outside the engine room in case the engine room is affected by the fire.
- **Total Flooding Systems** - are employed to discharge inert gas into areas such as machinery spaces to suppress a fire. This type of system is used in these areas because it may not be possible to fight the fire locally.
- **Foam systems** - may be installed, particularly where flammable liquids are present.
- **Water mist systems** - are employed for 'local protection' of key equipment such as diesel engines. These systems differ from conventional sprinkler systems because the water is delivered at high pressure through fine nozzles resulting in a fine mist. Diesel engines have high pressure fuel systems, and any leak may cause a fire. This video in the link below shows the dramatic effect of water mist on an oil fire - dlammable liquid pool fire test with HI-FOG water mist fire protection solution.

https://www.youtube.com/watch?v=ci9GayOcUp0 YouTube

The image below shows the bank of bottles for a CO_2 flooding system onboard a container ship.

Figure 10: Bank of bottles for CO_2 fire extinguishing flooding system, source Captain Colin Fardy.

8. Advantages and disadvantages of container ships

8.1 Advantages

1. Container ships are a key component that enable Global trade.
2. Ensures fast and efficient transport of goods.
3. Versatility as they can carry a range of cargoes.
4. Allows for economies of scale both in terms of the cost of transport and the cost of goods themselves.
5. Security of cargo as containers can be sealed and tracked.
6. They have regular, fixed schedules with predictable delivery dates.

8.2 Disadvantages

1. As a key component in global trade if it fails, global trade suffers. See the MV Ever Given incident in the Suez Canal.

   https://www.rte.ie/news/world/2021/0326/1206253-suez-canal-ship/
2. Due to operating in a harsh environment, there's always the possibilities of damage to containers, damage to the ship and loss of containers overboard.
3. Component failures onboard can lead to loss of the ship, temporarily or permanently.
4. Majority of containerships are still relying on fossil fuels for propulsion systems.
5. Due to technologies and communication methods used the industry has suffered from cyber-attacks, costing companies millions, and resulting in serious delays and issues within the logistics supply chain.

9. Conclusion

Indeed, container ships represent a remarkable combination of design and technology that has transformed the global shipping industry and international trade. Their innovative design and technology have led to numerous advantages and efficiencies in the movement of goods worldwide.

As an island nation, container ships are not only crucial for Ireland's international trade and transportation needs, but they are also a lifeline connecting Ireland with the rest of the world.

10. Glossary of terms

Ballast Water	When a ship has no cargo or a small amount of cargo, she needs weight to keep her stable, keep the propeller submerged and reduce the stresses on her. Thus, ships will take on sea water into special tanks called ballast tanks.
Cell Guides	Vertical metal structure that guides container into and out of the cargo hold. See Figure 3.
Draft	Point of which the weight of the ship may be considered to act.
GM	Pronounced as seen- 'Gee-Emm'. It is a term used as a measurement of stability. See stability term below.
Hogging	Where the middle of the ship bends upwards.
Hull	The main body of the ship, the part that keeps the inside watertight and provides protection for everything inside.
Intermodal	Movement of goods from one destination to another using several different methods of transport e.g., Truck, ship, train.
Sagging	Opposite to hogging, the middle of the ship bends downwards, sags.
Scrubbing system	Systems designed to remove potentially harmful particulate matter and components from ships exhaust gases.
Stability	Ability of a ship to remain upright or return to the upright position if pushed over to one side by an external force. GM Is how ship stability is measured. Knowing the GM gives you an indication of the stability of a vessel.
Steering gear	Mechanised equipment used to turn the rudder and thus the ship, usually a electro-hydraulic unit.
TEU	Twenty Foot Equivalent Unit. The measurement of a twenty-foot standard container. Used as an exact measurement to determine how much cargo a container ship can carry.
Torsion box	Keep part of the design and structure of a container ship. It is the underdeck 'box' that runs fore and aft given strength to the ship and helps prevent excessive torsional stress.
Vessel	Another word for ship.

11. Table of figures

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